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THE USE OF AN OPEN-CYCLE ABSORPTION SYSTEM FOR HEATING AND COOLING

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ABSTRACT

Solar cooling for commercial applications using open-cycle absorption refrigeration systems has been investigated and found to be feasible. If an open-cycle absorption system can be operated as a chemical heat pump for winter heating operation, the system would offer year-round operation that could make the system economically viable for many regions of the U.S. An analysis of heating operation for the open-cycle system is presented using a computer program that simulates heat and mass transfer processes for any environmental condition. The open-cycle absorption refrigeration system can be operated as a chemical heat pump. Simulations for winter heating operation were run for five U.S. cities, with solar COP's in the range of .06 to .16. At these levels, the OCAR system can provide full heating and cooling operation for office buildings in many southern U.S. cities.

1. INTRODUCTION

Solar cooling has received considerable attention from researchers in the U.S. and abroad in recent years. The year-round utilization of solar energy systems is attractive from both performance and economic standpoints. Open-cycle solar cooling systems have potential for applications in solar cooling. Open-cycle systems are characterized by the use of ambient air as a process fluid, thereby using the availability of energy in the environment for useful work. The open-cycle absorption refrigeration (OCAR) system is an example of technology that uses the environment in its process.

OCAR systems are based on the same chemical absorption cycle using a sorbent/refrigerant pair as that employed by the conventional closed-cycle absorption refrigeration systems. In the open-cycle system, however, the condenser is eliminated and refrigerant vapor is discharged to the environment. An outside source of refrigerant is then required to supply the evaporator. The use of water as a refrigerant makes the open-cycle process feasible. A number of sorbent solutions can be used, such as salt solutions of lithium chloride. A typical OCAR system using an open collector/regenerator is shown in Figure 1.

Open-cycle absorption cooling systems have been studied by several researchers. Collier (1) investigated the use of OCAR systems for cooling in several locations around the U.S. It was found to be technically feasible for all locations, with solar coefficients of performance (cooling output/solar input) in the range of .09 to .45. These values compared very favorably to solar COPs of .15 to .18 for solar closed-cycle absorption systems. The advantages of simpler and less expensive collectors, improved thermodynamic performance, and the adaptability to solar energy were found to be significant and pointed to the potential of the system in the field of solar cooling.

The full potential of the OCAR system lies in whether it can be used as a chemical heat pump, i.e., if the cycle can be operated in such a manner as to provide a useable heat source for winter heating operation, as well as provide a chilled water source for summer cooling operation. This type of system would have the attractive economics of year-round operation from a single machine. This study will investigate the possibility of such operation, the system configurations for a heating mode, and the performance of the systems in several locations around the U.S.

2. ANALYSIS OF HEAT PUMP OPERATION

2.1 System Operation

For operation as a heating system, the absorption process has the same system configuration as a cooling system, but operating parameters are changed to meet constraints necessary for a heating mode. The source of heat is the absorber, where the heat of absorption is removed. A key factor in the process is assuring that the system can deliver heat at a temperature level that is useful for space heating. To satisfy this requirement, the absorber is operated at a temperature of 45°C to assure a hot water source at 40°C.

Just as operation in the cooling mode requires auxiliary cooling towers to remove the heat of absorption, operation in the heating mode requires a

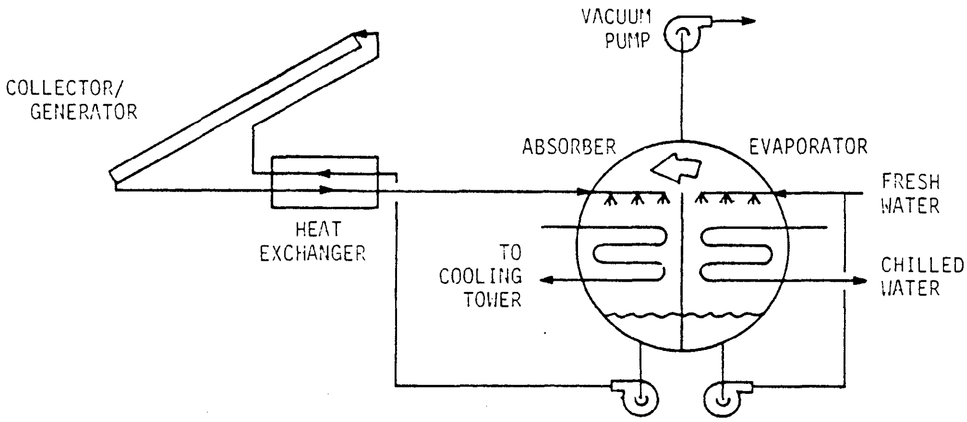

Fig. 1 Open – Cycle Absorption Refrigeration System

secondary heat source to provide the heat of vaporization for the evaporator. This heat source can be waste heat from other equipment, heat from solar collectors, or from sources such as ground water, available in many locations in the southern U.S.

The ability of the system to operate in the winter is dependent on the success of regenerating the lithium chloride solution in an open flow solar collector. The key factor is operating efficiently without the salt solution freezing on the collector under conditions of low ambient temperature and low absolute humidities. The heat and mass transfer relationships developed by researchers in the U.S.S.R (2,3) and used by Collier (1) for cooling system simulations are valid for all conditions of regeneration and can be applied to regeneration in winter conditions with adequate physical property data in the lower temperature ranges. Therefore, these basic relationships form the basis for simulations of system performance in the same five U.S. cities that were evaluated for cooling performance in Collier's study (1).

2.2 Simulation of Winter Operation

Hourly simulations were run for five U.S. cities: Phoenix, Arizona; Albuquerque, New Mexico; Dallas, Texas; New York, NY; Miami, Florida. TMY (Typical Meterological Year) weather data typifying long-term average conditions was used, with days chosen based on ASHRAE 97 1/2 per cent winter design conditions. This data is summarized in Table 1.

Many of the operating parameters of the OCAR system in the heating mode, such as salt solution concentration and temperature, are fixed by the required 45°C absorber temperature. Other system parameters, such as solution flowrate, collector length, heat exchanger effectiveness, and auxiliary heat source temperature, are variables that can be studied for their effect on performance. Analysis of the performance of the system is aided by identifying the change in chemical energy of the salt solution during regeneration (change in salt concentration) and the change in thermal energy (change in solution enthalpy) in relation to the total output of the system.

Table 2 presents the solar COP$_s$ (heating output/ solar input) for changes in solution flowrate, collector length, and heat exchanger effectiveness from the stated base case. System performance ranges from solar COP$_s$ of .186 in Phoenix to .058 in New York for the base case. As a basis of comparison, flat plate liquid collectors would typically perform at solar COP$_s$ of .20 to .25 on a seasonal basis for space heating applications.

In examining the results of the simulations, it is apparent that large changes in solution flowrate and collector length have minimal effect on the solar COP. This is due in part to a balancing

TABLE 1. TMY WEATHER DATA USED FOR DAILY SIMULATIONS

City	Dry Bulb Temperature (°C)	Representative Day of Year
Phoenix	1.1 °C	Jan. 2
Albuquerque	-8.9 °C	Jan. 21
Dallas	-5.6 °C	Jan. 5
New York	-9.4 °C	Jan. 19
Miami	9.4 °C	Jan. 2

TABLE 2. SOLAR C. O. P MAPPING OF OCAR SYSTEM PERFORMANCE*

City	Flowrate (kg/m/1hr)				Length (m)			Heat Exchanger Effectiveness		
	62.5	125	187.5	250	16.7	25	50	0	0.7	1.0
Phoenix	.179	.186	.189	.190	.187	.186	.183	.156	.186	.187
Albuquerque	.155	.161	.163	.163	.162	.161	.156	.098	.161	.160
Dallas	.125	.127	.129	.128	.123	.127	.133	.025	.127	.130
New York	.058	.058	.058	.056	.051	.058	.068	-.195	.058	.061
Miami	.071	.070	.069	.068	.061	.070	.082	-.039	.070	.074

*Base case: Evaporator temperature = 15°C
Length = 25 m
Flowrate = 125 kg/m/hr
Heat exchanger effectiveness = 0.7

effect between thermal and chemical energy contributions to the total output. When the chemical output decreases and less water is lost during regeneration, the thermal energy of the solution increases because less energy is being taken for heat of vaporization. The presence of the heat exchanger does have a significant effect on the performance of the system, often making the difference between success and failure of operation in the heating mode. By buffering the absorber from low ambient temperatures, the system is able to maximize the chemical output and minimize thermal losses.

Figure 2 shows graphically the effect that evaporator temperature has on system performance. This is important because this relates directly to the temperature level of the auxiliary heat source. As expected, the performance increases as the evaporator temperature rises, and indicates that higher levels of performance can be attained using temperature sources of 20°C and above.

With solar COP's determined for heating operation and using values for cooling COP's from the study by Collier (1), the match between heating and cooling performance versus heating and cooling loads will demonstrate the applicability of the system as an integral utility system for commercial applications. Table 3 presents the proportional heating and cooling loads for office

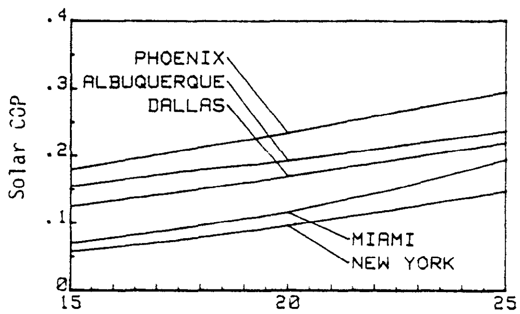

Fig. 2 OCAR Heat Pump Performance

buildings in the five cities as determined regionally in the AIA/RC Phase II survey of commercial buildings. (4) The accompanying ratios of solar COP's allow a determination of the fraction of heating load that could be expected from an OCAR system. The match is remarkable for Phoenix and Dallas, respectable for Miami, and, as one would expect, the colder climates of Albuquerque and New York would require full back-up capability. This comparison illustrates the applicability of the OCAR system as a year-round utility package.

TABLE 3. LOAD/PERFORMANCE MATCH FOR HEATING AND COOLING

City	Heating Load	Cooling Load	Load Ratio	Heating COP	Cooling COP	COP Ratio	Heating Fraction
Phoenix	32%	68%	.47	.19	.41	.46	98%
Albuquerque	62%	38%	1.63	.16	.43	.37	23%
Dallas	40%	60%	.67	.13	.21	.62	93%
New York	71%	29%	2.45	.06	.24	.25	10%
Miami	32%	68%	.47	.07	.22	.32	68%

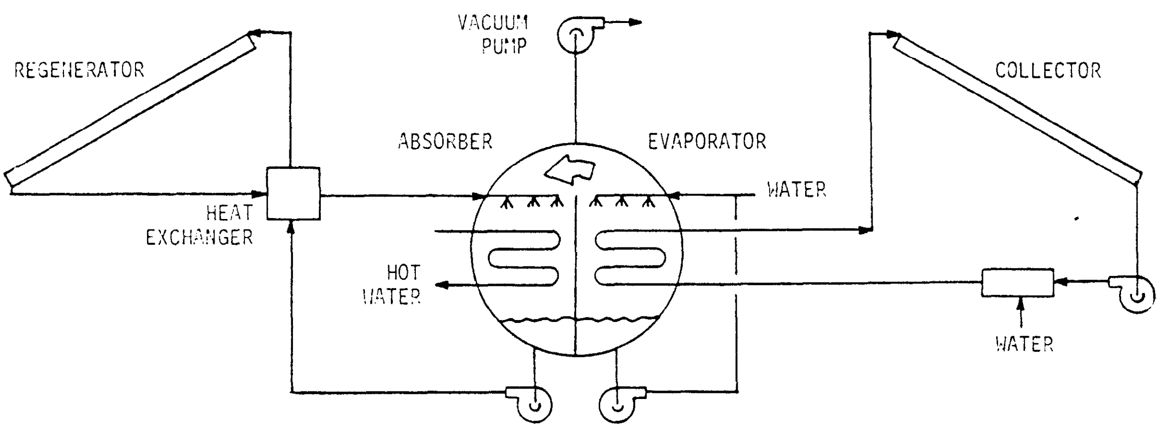

Fig. 3 OCAR Self Sufficient Heat Pump System

2.3 Self Sufficient OCAR Heat Pump

The previous section dealt only with the temperature of the auxiliary heat source and assumed a sufficient supply for full operation of the OCAR system. This would apply directly to waste heat applications and the use of ground water supplies for the auxiliary heat source. Even if these sources of heat are not available, the heating mode can still be operated using energy collected by a solar collector. Since a solar collector is built into the OCAR system, it is possible to use part of the collector surface as a thermal energy collector while the rest is used as a regenerator for the absorption cycle. This system configuration does require balancing the amount of heat required by the absorption cycle with the amount of heat that can be delivered by the thermal collector portion. Figure 3 is a diagram of such a system.

The ability of an open flow regenerator to function as a thermal collector introduces a new set of operating factors to optimize. Figures 4, 5, and 6 illustrate the effects of solution temperature, salt concentration, and flowrate to the collector on the energy outputs. Chemical changes must now be

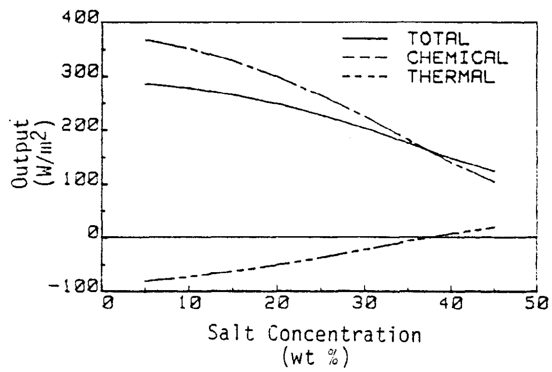

Fig. 5 Effect of Initial Concentration on Performance

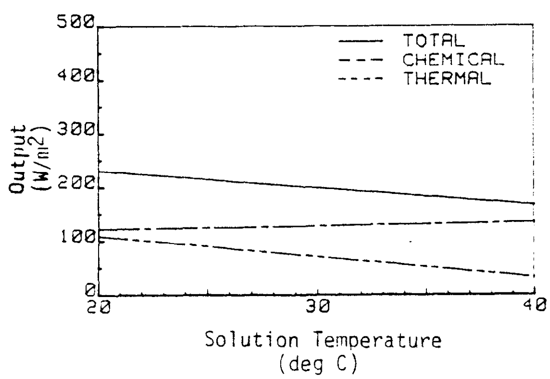

Fig. 4 Effect of Initial Temperature on Performance

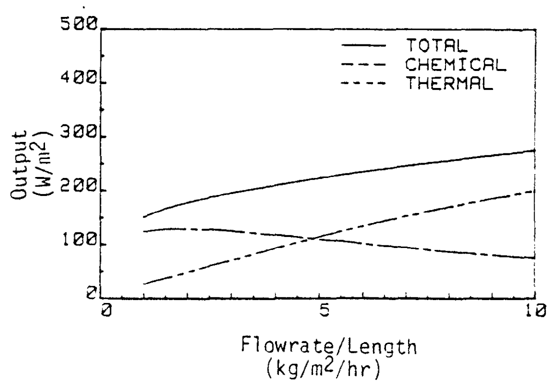

Fig. 6 Effect of Solution Flowrate on Performance

TABLE 4. EFFECT OF FLOWRATE ON SYSTEM COP'S
(Phoenix simulation using base case)

Flowrate (kg/m/hr)	Solar COP	Electrical COP
62.5	.066	13.4
125	.095	7.7
187.5	.112	4.5
250	.123	2.8

TABLE 5. PERFORMANCE OF A SELF-SUFFICIENT OCAR HEAT PUMP

City	Solar COP	% Collector as Heat Source	Electrical COP
Phoenix	.095	52%	7.7
Albuquerque	.086	50%	6.9
Dallas	.063	54%	5.3
New York	-	-	-
Miami	.046	46%	4.8

minimized while thermal output is emphasized. When operating as a thermal collector, the loss of water is a handicap, since more heat is lost by vaporization of water from the collector than can be recovered by adding make-up water and using the resulting heat of absorption. Based on these effects, the thermal portion of the collector should be run at the highest concentrations possible without freezing, at the lowest solution temperatures feasible without penalizing the performance of the absorption cycle, and the highest flowrates subject to constraints on pumping power. Table 4 illustrates the effect that soluation flowrate has on system performance. As flowrates increases, the solar COP increases, but is offset by a corresponding decrease in electrical COP, a measure of pumping power. For the system simulations, solution flowrate was set by the flowrate/length ratio of 5 (kg/m/hr)/m, solution temperature was fixed at 20°C for an evaporator temperature of 15°C, and salt concentration to the collector was set at 40 weight percent.

Table 5 is a summary of results from the simulation of self-sufficient OCAR heat pumps. As before, solar COP is given as cooling output/solar input, while electrical COP is cooling output/ electrical input based on the pumping power requirements for both the chemical and thermal portions of the collector. Because of the cold temperatures in New York, the self-sufficient system could not be operated without freezing. However, in all of the southern cities, the system performed at solar COP levels of .095 for Phoenix to .046 for Miami, with high values of electrical COP's from 4.8 to 7.7. Since the open flow collectors for the OCAR system are very inexpensive, these performance levels are cost-effective when compared to supplying the energy with flat plate liquid collectors.

3. CONCLUSIONS

The open cycle absorption refrigeration system can be operated as a chemical heat pump on a year-round basis. Simulations for winter heating operation were run for five U.S. cities, with solar COP's in the range of .06 to .16. At these levels, the OCAR system can provide full heating and cooling operation for office buildings in many southern U.S. cities. The system can operate using waste heat sources or can be energy self-sufficient through the use of part of the collector for thermal energy collection.

These results point to increased utility of the OCAR system for HVAC applications and enhanced economics due to annual usage of the system. Operating as a chemical heat pump, the OCAR system offers a promising alternative to existing solar technology.

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